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Progress Report

TESTS WITH INSECTICIDES TO CONTROL THE LODGEPOLE NEEDLE MINER

1956 and 1957 Seasons

By

Galen C. Trostle and Charles B. Eaton

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CALIFORNIA FOREST AND RANGE EXPERIMENT STATION
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U.S. DEPARTMENT OF AGRICULTURE - FOREST SERVICE
CALIFORNIA FOREST AND RANGE EXPERIMENT STATION
Division of Forest Insect Research

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SUMMARY

In 1956 and 1957, four field tests of insecticides for controlling the lodgepole needle miner in lodgepole pine were conducted in cooperation with the National Park Service. Two of the tests were made in June and September 1956 against 2nd and 4th-instar larvae; two were in July and September 1957 against moths and 1st-instar larvae. The areas treated are at Tuolumne Meadows, Yosemite National Park.

The 1956 sprays were applied with an orchard-type mist blower; the 1957 sprays were applied with a helicopter. Endrin, dieldrin and malathion were used in the fall of 1956. All other tests were with malathion.

A mist blower application of 2.5 pounds of malathion emulsion in 200 gallons of water per acre showed good control. Similar applications of endrin, dieldrin and malathion in fuel oil at a per-acre rate of 2 pounds of insecticide in 20 gallons showed good results when sprayed directly on the foliage, but poor results when sprayed so as to drift onto the trees.

It was determined that a 200 hp. Bell helicopter could be operated successfully with a 20-gallon load of spray, at elevations of 8,000 to 9,000 feet above sea level where the needle miner-infested stands occur. Oil sprays of malathion, applied with the helicopter to control the adults, killed large numbers and reduced the population of larvae that subsequently became established by 75 percent. The same insecticide, applied at a rate of 2 pounds in 20 gallons of fuel oil per acre to control newly hatched larvae, killed about 72 percent.

Test procedures are described and the results of the studies presented and discussed in this report. The report also contains suggestions for future tests.

INTRODUCTION

During the past five years the most extensive single insect outbreak in California has been the lodgepole needle miner, Recurvaria milleri Busck, in Yosemite National Park. The needle miner is a small moth that attacks lodgepole pine. The larvae of this moth defoliate the trees by boring into and hollowing out the needles. The insect has a 2-year life cycle, most of which is spent in the larval stage. It reaches the adult stage in the odd-numbered years. During epidemic periods the needle miner may destroy most of the foliage of its host, causing the tree to die outright or to fall prey to attacks by the mountain pine beetle, Dendroctonus monticolae Hopk. No satisfactory method of control is known.

In order to learn how needle miner outbreaks can be prevented or suppressed, Experiment Station entomologists, cooperating with the National Park Service, are conducting studies of the problem. The present studies were started in 1954 and have been in progress since then. One of the goals is to perfect insecticidal methods for use against the needle miner. Research toward this goal reached the field-testing stage in 1956. During 1956 and 1957, four field tests involving several different chemicals, methods of application, and stages of the insect were conducted. This report contains an account of these tests and the findings.

The Experiment Station prepared the plans for the tests, subject to concurrence of Yosemite National Park, (Trostle, 1956a, 1956b, 1957). The Station supervised the entomological phases of spraying operations and collected and analyzed the data. The Yosemite National Park designated the areas to be sprayed and furnished labor, materials, and equipment for the tests. In 1956 all of the spraying was done with Park Service crews and equipment. In 1957 spraying was contracted to Southwest Helicopters. Malathion for tests in 1956 was supplied by American Cyanamid Company; endrin and dieldrin by California Spray-Chemical Company and Shell Chemical Corporation.

The Station's responsibilities in these tests were handled by G.C. Trostle, except for the phases relating to needle miner development. These were the responsibility of G.R. Struble. Assistance was also furnished by other members of the Station, principally R.C. Hall, P.H. Lord (in 1957), and J.H. VrMeer (in 1956). The Park's responsibilities were handled by Park Forester Emil Ernst.

EXPERIMENTAL AREA

The lodgepole pine forests where the needle miner problem occurs are located in Yosemite National Park on the upper Tuolumne and upper Merced River watershed. These forests are valued chiefly for recreational and aesthetic purposes, rather than as a source of wood products.

In them the lodgepole needle miner has been a recurrent problem since it was first discovered in 1903. Aided by the mountain pine beetle, which seems to become epidemic in lodgepole in the wake of needle miner outbreaks, the needle miner has caused widespread tree-killing. The result in many places is a forest of snags. Experimental work has been aimed primarily toward control of the needle miner to prevent tree mortality, particularly around campgrounds and other high-use areas.

The most recent needle miner outbreak began about 1947 and has been in progress since. The infestation is centered around Tuolumne Meadows, a heavily used recreational area, and in the last decade the area infested has increased until it now comprises some 50,000 acres. The mountain pine beetle broke out in the northern part of the infestation area in 1952 (Hall and Wickman, 1953), and has been steadily increasing since.

The lodgepole around Tuolumne Meadows grows in almost pure, even-aged stands, with probably less than 10 percent in other species such as hemlock and red fir. The stands are either mature (over 200-years old) or young (under 60 years). Trees in the mature stands average about 26 inches in diameter breast high and range up to 50 inches d.b.h. Those in the young stands average 6-10 inches d.b.h. and range up to about 16 inches. The young stands originated following earlier insect outbreaks around the turn of the century. The elevational range of the infested stands is 8,000 to 10,000 feet above sea level. The terrain in this general area is quite rugged, and characterized by high granite ridges and domes. Most of the lodgepole grows on the lower slopes and along stream bottoms where the ground is less precipitous.

REVIEW OF RECENT STUDIES

Research on the biology, ecology and control of the needle miner has been conducted intermittently since the insect was first reported over 50 years ago. Most of the studies have been carried on during outbreaks. The most recent investigations were begun by G.R. Struble (1955b) in 1954. In all, except the earliest outbreak period, insecticides for controlling the needle miner have been tried. Several sprays tested prior to 1954 were effective in killing the insect, but were impractical for field use. This was due either to the large volume required or to lack of satisfactory methods of application.

In the 5-year period preceding 1954, aircraft spraying with some of the insecticides that became available after World War II was tried. Attempts made in 1949 to use a Stearman biplane and a helicopter to spray needle miner-infested stands were failures. Neither craft could be operated satisfactorily over the test area, due to the terrain and elevation. In 1953 a second attempt was made to control the insect with sprays. This was a large-scale test in which 11,000 acres of the infestation was sprayed

with an oil solution of DDT at a per-acre rate of 1 pound per gallon of spray. A B-18 bomber, converted for spraying, was used, and the spraying timed to kill the newly hatched larvae. This attempt likewise failed, apparently because not enough of the toxicant reached the insect to have any appreciable effect (Hall, 1956).

These failures led to a return to small-scale tests, designed to screen other materials for possible use against the needle miner. In 1954 and 1955 G.R. Struble conducted tests of this type. He used hand-spray equipment to treat infested branches, or in some cases small trees, with a number of different insecticides and at various stages of needle miner development. The results of the 1954 tests indicated that malathion, endrin, and dieldrin sprays were superior to DDT against the larvae. (Struble, 1955a). In 1955 these same insecticides, with the addition of heptachlor, were tested against the pupae and adults. Pupae were hard to kill with all of the insecticides while the adults were easily killed, particularly with malathion (Struble, 1956).

Field tests of insecticides for controlling the needle miner were conducted at Tuolumne Meadows in 1956 and 1957. These tests were predicated on the results of Struble's studies. The general objectives were (1) to learn whether materials that showed promise from these studies could be used successfully on an operational basis to control the needle miner; and (2) to evaluate equipment for applying the insecticides.

MIST BLOWER TESTS - 1956

The experiments conducted in 1956 were against the larval stage of the needle miner inside the needles. Their specific purpose was to determine (1) whether doses of insecticide, comparable to those ordinarily applied by aircraft to control other forest defoliators, could be used effectively against this insect; (2) if not, what dose was needed? Information on the first of these points was sought in trials with malathion in the spring. The second point was considered in trials with malathion, endrin and dieldrin in the fall. These tests are discussed separately below.

Due to the difficulties encountered in previous experiments with aircraft spraying in this area, an orchard-type mist blower was used in the 1956 tests. By substituting this machine for an aircraft, smaller plots could be sprayed and a greater variety of application rates tested. The mist blower was also less costly to operate, and with it spray delivery could be more closely controlled. The machine used was a Bean Rotomist, model 100E, towed behind a Dodge powerwagon (figures 1 and 2).

Spring Experiments

The first ground tests, carried on in June, were with oil solution and water emulsion sprays of malathion against 2nd and 3rd instar

Figure 1.--Truck towing mist blower used in 1956 tests. Blower is cement-mixer type, powered by a 4-cylinder engine mounted behind. Fifty-gallon tank in base.

Figure 2.--Blower in operation spraying needle miner-infested trees. Blower can be rotated by operator through 360 degrees horizontally and about 105 degrees vertically.

needle miner larvae (Trostle, 1956a). Malathion was selected since Struble (1955b) found it to be more effective against the larval stage than the other insecticides tried. The tests with the oil solution, as stated above, were intended to simulate aircraft spraying. The water emulsion was tried to check the effects of using a larger amount of carrier.

The area in which the spray trials were made was a young lodgepole stand along the Tioga Road (figure 3). For the oil spray tests, two 4-acre plots (1J, 2J) each 20-chains long by 2-chains wide, were established. These were within the first $1\frac{1}{2}$ miles of the east end of the old road and bordering upon it. The emulsion was tried on 20 trees on the edge of the road at the west end of the improved section. The area covered by these tests was estimated to be $\frac{1}{4}$ acre (3J).

An emulsifiable concentrate containing 55.7 percent malathion was used in formulating the spray materials to be tested. The oil solution was prepared by mixing 1 gallon of the concentrate, containing 5 pounds actual malathion, with 4 gallons of fuel oil. The application rate tested was 4 lbs. malathion/4 gals. spray/acre. The water emulsion consisted of 1/8 gallon of the concentrate, containing 5/8 pound malathion in 50 gallons of water. The rate of application tested was approximately 2.5 lbs. malathion/200 gals. spray/acre.

The mist blower used to apply the spray was fitted with a #4 nozzle and 5-hole spinner which allowed the spray to be discharged at 1.75 gallons per minute. On the oil spray plots, the blower was directed so that the discharge stream was at an angle of 60° above the horizontal and 90° to the line of travel (figure 2). Thus the spray was blown over the tops of the trees and drifted down on them from above, similar to the spray from an airplane. On the emulsion spray plot, the insecticide was sprayed directly on the foliage. All of the spraying was done on June 27.

In advance of the spraying, trees from which samples would be taken to determine the effects of the treatments were marked on the plots and on nearby check areas. On the oil spray plots oil-sensitive cards were also located near each tree to show the distribution of the spray. Seventy-five trees were marked on each of these plots. These were in 3 lines, 25 trees per line. Line 1 was 20 feet from the road; line 2 was 70 feet and line 3 was 120 feet. Check trees were located on the opposite side of the road and over $2\frac{1}{2}$ chains from the spray plots. The sampling unit was a 10-needle sample from each of 2 tips per tree on plots 1J and 2J, and 4 tips per tree on plot 3J and the checks. Tips were collected with pole pruners (figure 4) at a height of about 20 feet above the ground, usually in the lower third of the crown. In the prespray sampling, 10 needles were picked at random, from the last two needle whorls on the tip, without regard to whether or not they were mined. Counts were then made of the living and dead larvae. In the postspray

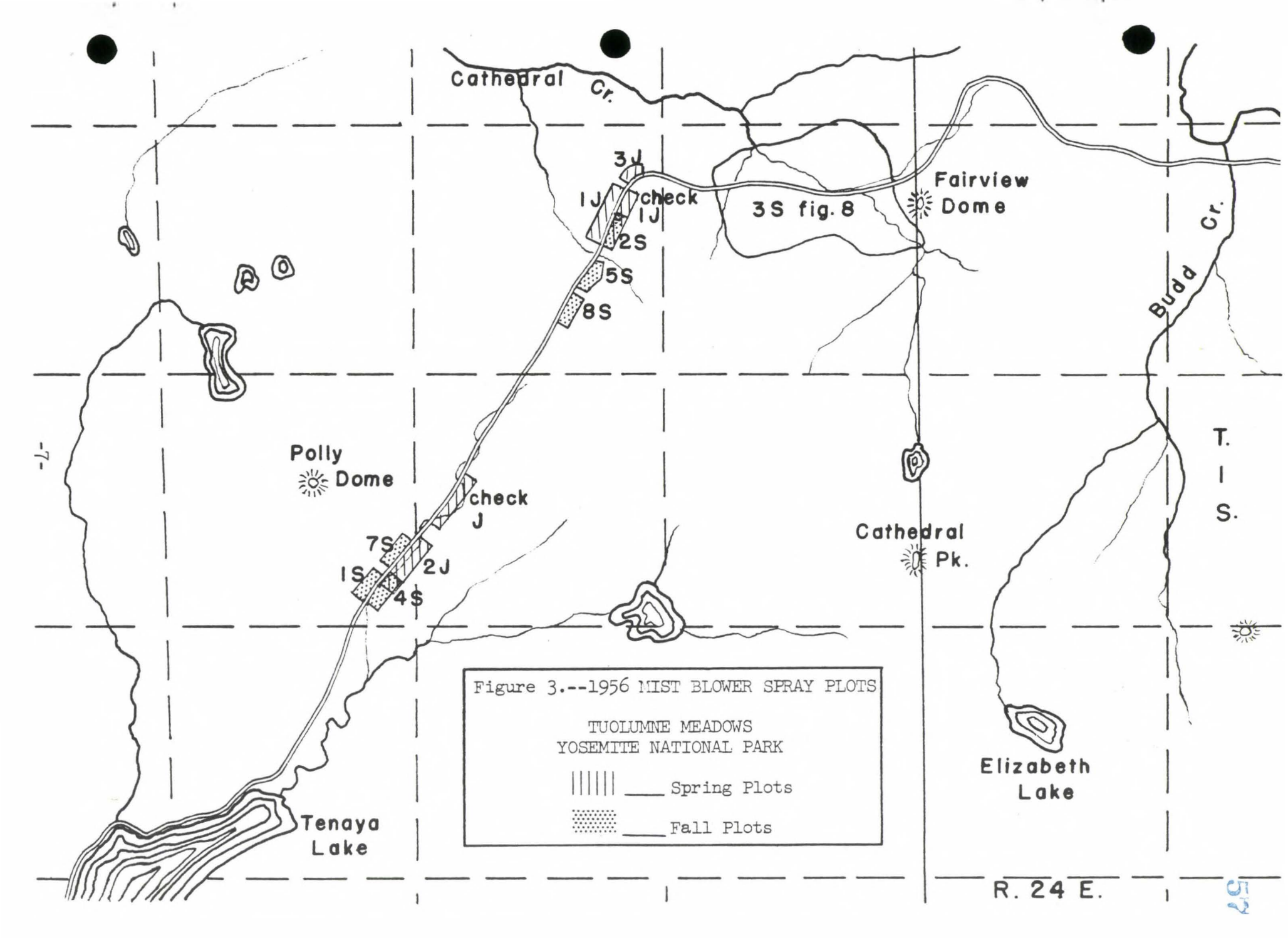


Figure 3.--1956 MIST BLOWER SPRAY PLOTS

TUOLUMNE MEADOWS
YOSEMITE NATIONAL PARK

||||| ____ Spring Plots

____ Fall Plots

Figure 4.--Collecting samples of lodgepole pine foliage to check needle miner mortality due to spraying.

Figure 5.--Spraying when the moths were in flight produced kills like this, averaging in one test 337 moths per square foot.

sampling, the size of the sampling unit was the same but only mined needles were used. Prespray samples were collected just before spraying; postspray samples were taken two weeks later.

The results of the tests are summarized in table 1. On the two plots sprayed with malathion in oil to simulate airplane application, control was unsatisfactory. Mortality due to the insecticide was less than 23 percent. On the third plot, where the malathion emulsified in water was distributed in a large volume of the carrier, more satisfactory results were obtained. Control was slightly more than 84 percent.

Table 1.--Control of needle miner larvae with malathion spray applied by mist blower, June 1956 tests

Plot no.	Type of application	Per acre dose: Insecticide (Lbs.)	Per acre dose: Carrier (Gals.)	No. of 10-needle samples	No. of live larvae per sample: Prespray	No. of live larvae per sample: Postspray	Control (Percent)
1J	Overhead	4	4	150	3.21	5.72	16.3
2J	Overhead	4	4	150	2.59	4.26	22.8
3J	Direct spray	2.5	200	80	2.49	0.84	84.2
Check plots				200	2.95	6.28	

An analysis of the oil-sensitive cards showed that no significant needle miner mortality was found where the volume of spray deposit was below $1\frac{1}{2}$ gallons per acre. Where $1\frac{1}{2}$ to 4 gallons of spray reached the tree, mortality increased to a maximum of about 68 percent. The results were quite variable; however, the lowest spray deposits occurred on the cards farthest from the mist blower.

The data from the check trees indicated that in the 2 weeks between pre-and postspray samplings, the number of live larvae in the totals counted increased from 62.8 percent to 68.5 percent. This increase might have been due to sampling error, but is more probably due to the migration of larvae to the newer needles, as described by Struble (1957).

The results of the spring tests showed that insecticide doses, comparable to those ordinarily put on with aircraft to control many other forest defoliators, were not effective against the needle miner. They indicated that insecticides with a higher proportion of carrier were needed.

Fall Experiments

The second series of ground spray experiments in 1956 were conducted in September. They were planned (Trostle 1956b) to determine the lethal effects of endrin, dieldrin and malathion in comparatively high volumes of oil. Oil was selected because it is a better carrier than water in many respects. These tests were also against the larvae, at this time mostly in the 4th instar.

For the September tests, 6 spray plots were established in young-growth lodgepole bordering the old Tioga Road, between Tenaya Lake and the east end of the unimproved section (figure 3). Three of the plots (2S, 5S, 8S) were 2 acres in size (10-chains long by 2-chains wide). Three (1S, 4S, 7S) were 1 acre in size (10-chains long by 1-chain wide). All were parallel and adjacent to the edge of the road. Two check areas were selected on the opposite side of the road across from the spray plots.

The insecticide concentration and rate of application were the same for all three materials tested. The concentration was 1 pound of insecticide dissolved in 10 gallons of fuel oil. The rate of application was 2 lbs. insecticide/20 gals. fuel oil/acre.

As before, the plots were sprayed with the mist blower; but two different methods of application were used. In the first method, the blower was directed the same way as in the spring. In the second method, the blower was directed at the tree crowns and moved continually up and down so as to cover the crowns from top to bottom. Three spray passes were made by each plot, with the blower directed at a different angle to the direction of travel on each pass so that the spray would reach all sides of the tree as far as possible. The first pass was made with the blower at 30°, the second at 90°, and the third at 150°. The three 2-acre plots were sprayed on September 19 by the overhead method. The three 1-acre plots were sprayed on September 20 by the direct method.

To determine needle miner mortality from the insecticides, the larval population was sampled before and after spraying. On the 2-acre plots, where the spray was applied overhead, the same plan used in the spring tests was followed in marking trees for sampling; i.e., 3 lines of 25 trees each, 20-, 70- and 120-feet distant respectively from the road. On the 1-acre plots, where the spray was directed at the tree crowns, 25 trees located on the edge of the road were sampled. On the two check areas, the number of trees sampled was also 25 apiece. Pre- and postspray populations on the test plots were determined by the same system used previously. Prespray counts of the larvae were from 10 needles taken at random in the last whorl. Three tips were sampled instead of two as was done in the spring tests. About 12 days after spraying, the postspray samples were collected. These were put in plastic bags and brought to Berkeley in refrigerated cans. There they were stored under refrigeration until the surviving larvae could be counted.

Oil-sensitive cards placed near the sample trees were used to determine the distribution of the spray. On the plots where the spray was put on overhead, the cards were placed in the open as near as possible to the base of each marked tree. On the direct spray plots, 3 cards were placed on the bole of each marked tree, excluding the side away from the road. Most of the cards were completely covered with oil after spraying so that it was not possible to estimate the dose received by each tree.

The data from the fall tests are summarized in table 2. They show that (1) the highest kills were obtained in trees closest to the line of spray release, and (2) the direct method of application resulted in greater mortality than the overhead method. With the direct method, from 92 to 95 percent of the needle miners were killed, the highest kill being with malathion. Overhead spraying was much less effective, and beyond 70 feet from the point of discharge the spray had a negligible effect. With this method, endrin killed a higher proportion of larvae than dieldrin or malathion; however, the maximum kill was only 81 percent. These tests confirmed previous findings that a large volume of spray is necessary to control needle miner larvae. Also they indicated that if a large enough volume is used, endrin, dieldrin and malathion all are about equally effective against larvae inside the needle.

HELICOPTER TESTS - 1957

From the start of the field tests in 1956, it was recognized that much of the area infested by the needle miner could not be sprayed with a mist blower because it was inaccessible. To spray areas away from roads, aircraft would be needed. The information developed in the mist-blower tests indicated that aerial spraying might be feasible. Consequently, in 1957, this method was tried against the adults and newly hatched larvae. The insecticide selected for these tests was malathion, due to its performance in previous experiments. Endrin was eliminated because of its high mammalian toxicity.

In view of the terrain, difficulties previously encountered in using fixed-wing craft, and the absence of a suitable landing place for airplanes within the infestation area, the helicopter seemed to be the most practical aircraft for the tests. A helicopter was chosen on the assumption that if it could be operated at all at high elevations like those at Tuolumne Meadows, it would (1) drive the spray down into the trees rather than allow it simply to settle down; and (2) it would permit the spray to be more easily and accurately placed on the plots. The machine obtained was a Bell helicopter, Model G, powered in the first tests with a 200 hp., and later with a 210 hp. engine (figures 6 and 7). It was operated from heliports at Tuolumne Meadows.

Adult Sprays

In July, the first of the 1957 helicopter spraying experiments was conducted (Trostle, 1957). The objectives were twofold: first, to

Table 2.--Control of needle miner larvae with endrin, dieldrin and malathion spray applied by mist blower, September 1956 tests

Plot no.	Insecticide 1/	Distance from blower	No. of 10-needle samples	No. of live larvae per sample: Prespray	No. of live larvae per sample: Postspray	Control
Direct spray		Feet				Percent
1S	Endrin	10 - 20	75	7.92	.53	93.2
4S	Dieldrin	10 - 20	75	7.04	.59	91.5
7S	Malathion	10 - 20	75	7.21	.36	94.9
Overhead spray						
2S	Endrin	20	75	6.33	1.15	81.4
		70	75	4.77	2.68	42.2
		120	75	6.05	4.49	23.9
5S	Dieldrin	20	75	5.29	4.48	13.1
		70	75	4.79	4.95	0.0
		120	75	5.41	5.24	0.7
8S	Malathion	20	75	6.07	2.97	49.8
		70	75	5.32	5.27	0.0
		120	75	5.77	5.40	4.0
Checks	None		150	5.09	4.96	

1/ Applied at the rate of 2 pounds insecticide in 20 gallons of oil per acre.

determine if the helicopter could be operated satisfactorily in spraying lodgepole at Tuolumne Meadows; and second, to find out if the moths could be controlled and oviposition prevented with malathion, as indicated from Struble's studies (1956).

For the tests, three 20-acre plots in mature lodgepole stands were established. One was 5 x 40 chains in size, and the other two each 10 x 20 chains. The long plot (1) was located on the east side of Lembert Dome. Of the two shorter plots, one was on the west side of Lembert Dome (2) and the other in the lower Dingley Creek drainage (3). Check areas were located at least 10 chains away from each plot (figure 8). The corners of the plots were marked with strips of white butcher paper so that they could be seen from the air. The strips were laid on the ground

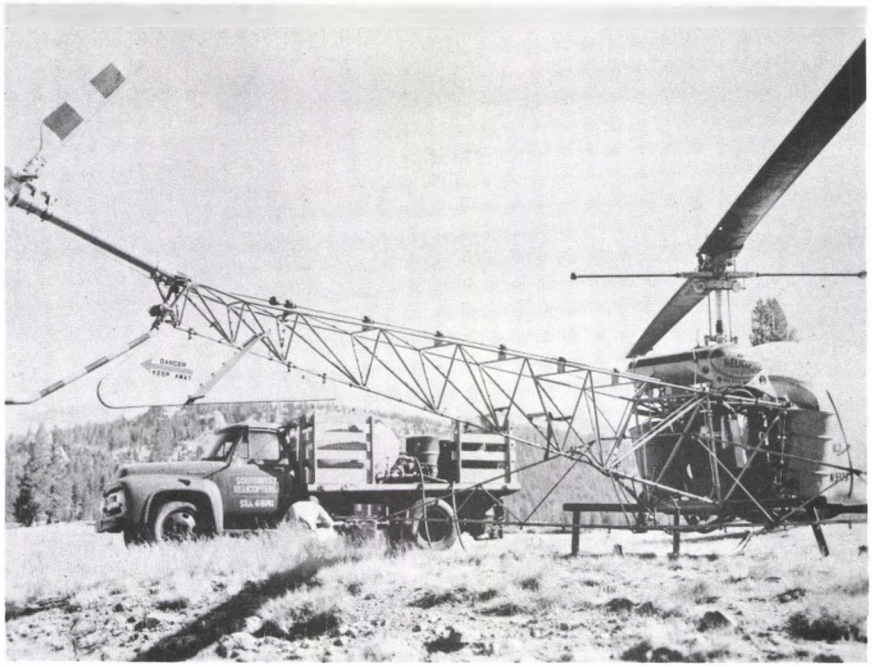
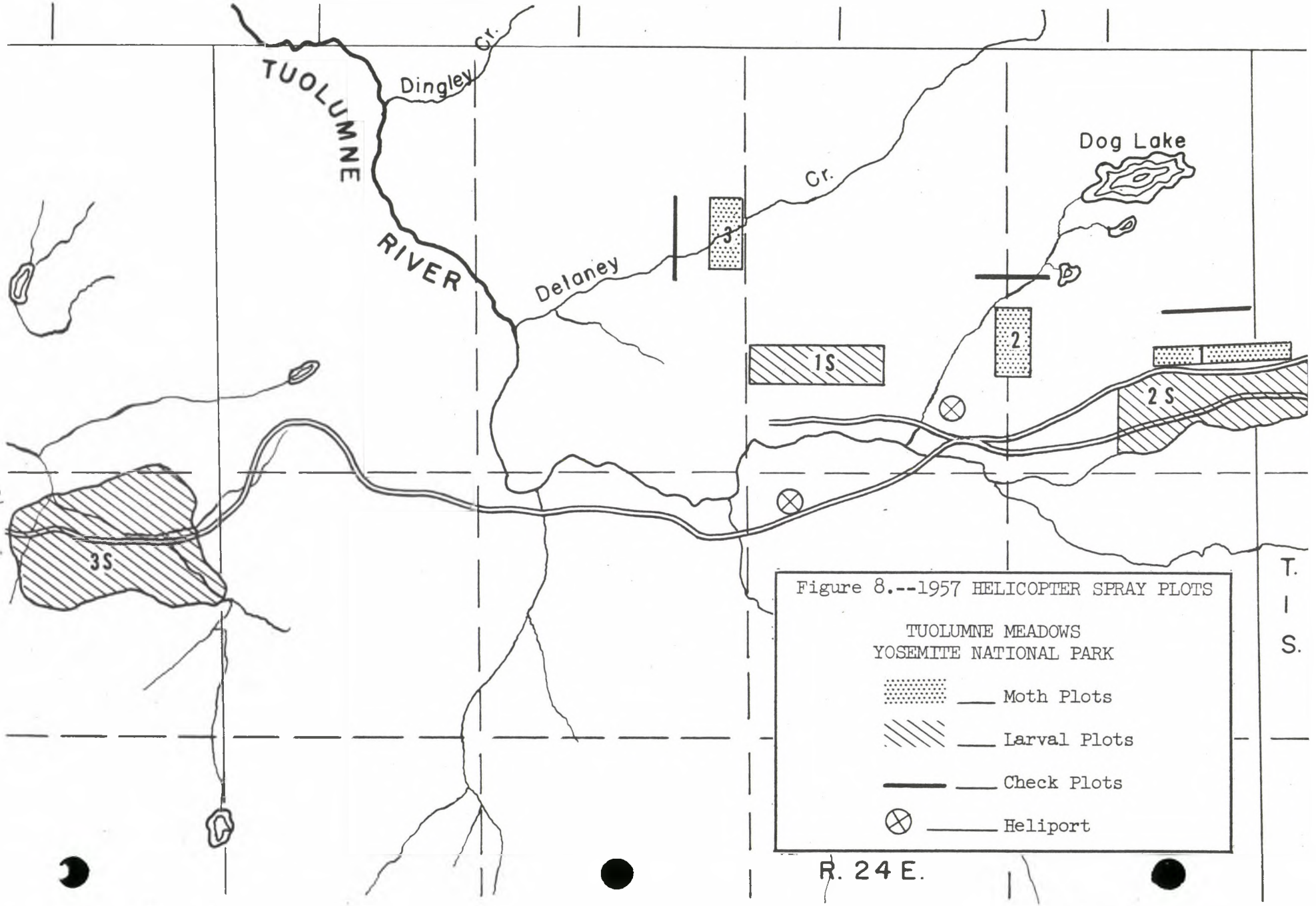


Figure 6.--Pumping insecticide from truck into the helicopter tanks preparatory to spraying.

Figure 7.--Spraying malathion by helicopter to control the needle miner.


TUOLUMNE RIVER
Dingley Cr.
Delaney Cr.
Dog Lake
3
1S
2
2S
3S
T. 1 S.
R. 24 E.
Figure 8.--1957 HELICOPTER SPRAY PLOTS
TUOLUMNE MEADOWS
YOSEMITE NATIONAL PARK
Moth Plots
Larval Plots
Check Plots
Heliport

in the form of a right angle, with one leg 15 feet and the other 20 feet long. (These lengths proved adequate, although longer strips would have been desirable, particularly under heavy cover.)

The insecticide was malathion dissolved in diesel oil. Two concentrations were prepared, using the 55.7 percent emulsion concentrate as in 1956. One contained 1 pound of actual malathion in 1 gallon of oil, and the other contained 1 pound in 10 gallons of oil. Three application rates were tested: 1 lb. malathion/1 gal. spray/acre; 1 lb. malathion/10 gals. spray/acre; and 2 lbs. malathion/20 gals. spray/acre.

The helicopter used in the July tests was rigged with two 12-foot booms containing 32 nozzles (Spraying Systems Company Teejet). It was calibrated in test flights to deliver 20 gallons of spray per minute. In treating the plots, flights were made at a speed of 20 miles per hour, at 50 feet or less above the general level of the crown canopy. Spraying operations were conducted just after daybreak when the air was relatively calm. The spray load carried was 20 gallons. The plots were sprayed on July 25 and 26. At this period, needle miner moths were about at the peak of emergence and oviposition had barely begun, according to biological studies made concurrently with the spray tests by Struble.

Oil-sensitive cards were used to reveal areas missed in spraying. These were placed in the open on each plot, as near as possible to trees marked for population sampling. The cards were distributed in the morning before spraying began and gathered as soon as spraying was completed. No attempt was made to determine the total amount of spray deposited on the cards, for the application rates (except for the 1-gallon treatment) were higher than the standard reference cards available.

The effects of the treatments on the needle miner were measured in two ways: (1) by drop cloths to collect dead moths; and (2) by pre- and postspray samples of the population in the needles. Drop cloths were used to show only whether or not moths were killed; they did not provide data on the effectiveness of the spraying, because they did not show the number not killed and degree of reinfestation in the plots. This was determined from sampling of the 1957-1959 population in the needles.

The drop cloths were of muslin and each 2 square yards in area. They were made by suspending from its corners a 3 x 6 foot piece of muslin on 3-foot posts and weighting down the center. Five drop cloths were erected on each plot, four at the corners and one in the center. Daily collections of dead moths that fell on the cloths were made from July 25 to August 6.

Samples of the needle miner population in the needles before and after spraying were collected from 50 trees which were marked for the purpose on each plot. As in 1956, the tips from which the samples were taken were clipped from the tree with a pole pruner. They were usually

obtained from the lower third of the crown, at a height of about 20 feet above the ground. The prespray samples containing full-grown larvae and pupae of the 1955-1957 generation were collected July 12-18. Each sample was from a single tip per tree. The count was of the number of live insects in 10 needles taken at random from the last two whorls.

Postspray sampling was delayed until the 1957-1959 generation larvae could become established, since Struble (1956) found the egg population could not be reliably sampled. The postspray samples were collected October 23-25, and brought to Berkeley where they were examined. The postspray samples were taken in the same manner as the prespray samples except that the number of tips was doubled (10 needles from each of two tips). The count was of the number of larvae that began mines rather than of the number living within the mines. This procedure was used on the assumption that it would reflect more realistically the effectiveness of the spray in controlling the moths.

Data from the tests against the moths are summarized in tables 3 and 4. The drop cloth counts (table 3) show that malathion had almost an immediate effect against the adults. They also show that this effect (figure 5) was greatest with the largest dose (20 gals.) and least with the smallest dose (1 gal.). The 10-gal. dose was intermediate in effect. Moreover, the data indicate that malathion had a substantial residual effect, for after 13 days, when the counts were discontinued, the daily kill was substantially higher in the two heavier treatments than in the checks. On the 20-gal. plot after spraying, a search was made for live moths; however, none were observed. This suggests that the number of survivors was not great, for in untreated areas of the same time live moths were very numerous. Difficulties were experienced in keeping drop cloths intact during the 13 days they were in use. Most were destroyed by animals. Deer ran through them or chewed on them; smaller animals removed pieces for nesting.

The extent to which the spray kept the moths from reinfesting sprayed areas is shown by the larval counts (table 4). The data indicate that all three doses of malathion prevented the next generation from becoming established to some extent. Best results were with the 20-gallon dose, which reduced the larval population by 75 percent. The 10-gallon dose gave 68 percent control; however, the 1-gallon dose had a negligible effect.

Larval Sprays

The tests against the moths demonstrated that spraying needle miner-infested lodgepole with a helicopter was feasible in spite of the high elevation of the stands. When this became apparent, plans (Trostle 1957) were activated for spraying a larger area in the fall of 1957 by helicopter. The mist-blower experiments had shown that malathion sprays would kill the larvae. The purpose of the fall test, therefore, was to learn what could be done against the larval stage with the same insecticide applied by helicopter.

Table 3.--Number of dead moths per square foot collected on drop cloths following helicopter spraying with malathion, July 1957 tests 1/

Date	Per acre dose (lbs. of insecticide and gals. of spray)				
	1 lb. 10 gals.	2 lbs. 20 gals.	1 lb. 1 gal.	None	None
Jul. 25	--	42.0	No sample	2.7	--
26	35.5	87.0	18.2	2.8	1.4
27	25.0	39.0	15.2	2.8	1.7
28	9.6	26.2	15.2	4.6	1.7
29	9.8	26.1	5.5	3.5	1.5
30	8.2	16.5	3.7	3.3	1.3
31	7.7	16.2	2.9	3.5	2.2
Aug. 2	12.6	34.1	4.6	5.4	2.1
3	12.5	17.1	3.5	3.8	1.9
5	8.7	18.2	1.8	2.9	2.1
6	5.9	14.5	1.8	2.5	1.3
Total	135.0	336.9	70.6	37.8	17.2

1/ Data from only 2 check plots are included in this table because of evidence of some spray contamination on the third plot.

Table 4.--Control of needle miner adults with malathion sprays, applied by helicopter, July 1957 tests. (Based on counts of immature stages.)

Plot no.	Per acre dose		Number of 10-needle samples		Number of live insects per sample		Control 3/
	Insecticide: Lbs.	Carrier: Gals.	Prespray	Postspray	Prespray 1/	Postspray 2/	Percent
Spray							
1.	1	10	51	98	2.27	1.93	67.6
2.	2	20	50	100	2.72	1.78	74.8
3.	1	1	50	100	2.90	5.69	9.6
Check							
1.	-	-	50	98	1.36	3.56	
2.	-	-	50	100	1.50	3.89	
3.	-	-	50	90	2.90	6.29	

1/ Living larvae and pupae.
2/ Larvae that began mines.
3/ Computed in each case on basis of data from corresponding check.

Three areas of mature lodgepole, totaling 330 acres, were selected for treatment. One (1S) was located north of the Sierra Club and was 40 acres in size. The second (2S) was west of the Curry Company camp and covered 90 acres. The third (3S) and largest was just west of the Cathedral-Tuolumne divide and extended over 200 acres (figure 8). The check areas for this test were the same as those used for the adult spray trials in July.

Malathion dissolved in diesel oil was the spray used on all three areas. The dose specified was 2 pounds of malathion in 20 gallons of fuel oil per acre. The concentration applied, however, probably was only six-tenths as strong, although this was not suspected until after spraying was finished. Due to the large quantity required, the spray mixture could not be readily prepared at the site. Consequently, specifications for the mixture were drawn up and the formulation contracted to a commercial concern. Two samples of the product supplied by this concern were taken. An analysis made by the Bureau of Chemistry, California Department of Agriculture, revealed that each sample contained only 0.06 pounds of malathion per gallon rather than 0.10 pounds as required.

The same helicopter used in the previous tests against the moths was used in September against the larvae. The nozzles on the machine were refitted with D-5 orifices and #45 cores (Spraying Systems Company Teejet). This change was made to decrease the size of the droplets to the specified range, 150-300 microns. Otherwise the spray equipment, methods of applying the spray, and conditions under which spraying was done were very similar to those in the earlier work.

Spraying against the larvae began on September 5 and ended September 16. During this period both eggs and young larvae were present. Biological studies by Struble (1958) showed that the eggs began to hatch during the last week of August. By September 5, 22 percent had hatched, and 91 percent of the embryos remaining were in the black-headed stage ready to hatch.

The following tabulation, from counts of 10 lodgepole pine tips taken from each of 4 areas, shows the status of needle miner development as of September 10-11.

	Number	Percent
Unhatched eggs	285	48.6
Larval entries (counted as larvae)	301	51.4
Total	586	100.0

When these samples were taken, over 94 percent of the unhatched eggs were in the black-headed stage. Records were not carried beyond this date, but probably most of the hatch was completed by the 3rd or 4th week in September.

Oil-sensitive cards were used to check the distribution of the spray deposit in the same manner as in the previous tests. The procedure for measuring the effects of the spray on the larval population was also the same. The samples from the sprayed areas were from 20 trees in the 40-acre area, 30 trees in the 90-acre, and 100 trees in the 200-acre. The ones from the checks were the same as those used in the adult spray tests. In analyzing the population data, the statistics for the three sprayed areas were pooled. This was also done for the three check areas.

The effects of spraying malathion to control the young larvae are shown by the data in table 5. An average of 72.3 percent of the needle miner population on the sprayed areas was killed by the insecticide. The degree of control ranged from 71.3 percent on the largest block to 78.1 percent on the smallest. If we consider the surviving population to be all larvae that began mines, disregarding those that died later inside their mines, then control was poorer - 66.6 percent average with a range of 66.3 to 69.4. Since all of the eggs probably had not hatched when spraying ended, it is possible that the 27.7 percent surviving were larvae from eggs that hatched after the spray had lost its effectiveness. This is speculative, however.

The conclusion from these results is that malathion killed two-thirds of the insects before they could enter the needles and an additional 6 percent inside the needles. The test did not show to what extent malathion sprayed with a helicopter would control larvae inside the needles. This is due to the fact that most of the spray was put on before the majority of the larvae had had a chance to enter the needles.

DISCUSSION

No better solution to the problem of controlling the needle miner than insecticides seems to be in prospect at present. For this reason the results of the field tests described in this report are of particular interest, especially those obtained in the last experiment. In a large-scale operation to control this insect, a workable aerial method, effective against the larvae, would be most valuable. The needle miner spends most of its life cycle in the larval stage; consequently a method that would control the larvae could be used throughout an entire season when it is in this stage. The results of these experiments show progress toward developing such a method. However, they do not show that this goal has been reached. From experience with other insects, we know that population reductions on the order of 75 percent are not adequate to prevent the early resurgence of outbreak populations. This degree of control however may be enough to keep the lodgepole alive, when it would otherwise die.

The 72-percent control obtained in the larval spray tests in September 1957 is probably a conservative figure. One of the most obvious reasons for believing this is that the strength of the spray presumably

Table 5.--Control of first instar needle miner larvae with malathion spray, applied by helicopter. September 1957 tests

Treatment	Per acre dose		No. of 10-needle samples[1]	No. of live insects per sample		Control
	Insecticide	Carrier		Prespray	Postspray[2]	
	Lbs.	Gals.				Percent
Sprayed	2	20	150	2.74	1.48 (2.16)	72.3 (66.6)
Unsprayed	-	-	150	1.92	3.75 (4.58)	

1/ Postspray samples twice the number of prespray except in unsprayed, where 288 were taken.

2/ Data in parentheses are larvae that began mines.

was below the concentration called for. The dose actually applied probably was 1.2 lbs. malathion/20 gals. oil/acre. A second reason is that the samples were taken in the lower part of the crown, where the needle miners may have been protected somewhat better from the spray. Spray is more likely to impinge upon the upper part of the crown than upon the lower part, for the upper crown is usually conical in shape, the foliage is less dense, and not as likely to be shaded from above. Furthermore, a greater proportion of needle miners occur in the upper third of the crown than in the lower third. Finally, mist-blower tests with malathion demonstrated that direct applications controlled 95 percent of the larvae. It seems reasonable to believe that control on this order could have occurred on the upper part of the canopy, which was not sampled.

The 2-pound dose of malathion applied by helicopter against the moths gave results comparable to those against the young larvae. The moth sprayings were not replicated, however, and the results therefore not as reliable. Possibilities for controlling this stage with sprays may be worth further consideration, particularly if large areas can be treated.

The 1957 tests met one objective aimed for. They showed conclusively that spraying operations in rough, high terrain such as that around Tuolumne Meadows are practicable with modern-day helicopters.

Some observations were made in connection with the spraying on the performance of the helicopter. One was that the ship did not seem to have as great an apparent effect in driving the spray down into the trees as was assumed at the outset. The spray cloud acted very similar to that from a fixed-wing ship. Partial information was also obtained on spraying time. In the July operations, the helicopter distributed 620 gallons of spray in 3.5 hours. In September, the volume was 6,600 gallons and the time 43.5 hours. These figures include spraying and ferrying time to and from the plots, but not loading time.

Further efforts are needed to improve helicopter spraying methods for controlling the needle miner, both to increase effectiveness and reduce costs. To facilitate future tests the following suggestions are made:

1. Representative samples of the spray mixture should be obtained before spraying and analyzed for content.

2. Wind measurements should be made as close as possible to the spray area, and spraying operations restricted to periods when wind movement does not exceed specifications.

3. If a large area is to be sprayed, it should be broken up into blocks that can be treated in one day. This procedure would make it easier to check the distribution of the spray and allow better ground control.

4. Before any spraying is done, the pilot should make an orientation flight with someone who knows the area, to become familiar with the location and shape of the spray blocks.

REFERENCES

Hall, R.C. 1956. The control of the lodgepole needle miner by the use of aerial application of DDT spray. Yosemite National Park. Season of 1953. CF&RES, Berkeley, Calif. 7 pp., illus. (mimeo.)

_____ and Wickman, B.E. 1953. Mountain pine beetle, Conness Basin, Yosemite National Park. August, 1953. Appraisal survey. Forest Insect Laboratory, Berkeley, Calif. 4 pp., illus. (mimeo.)

Struble, G.R. 1955a. Tests of new insecticides to control the lodgepole needle miner. CF&RES, Berkeley, Calif. 8 pp. (mimeo.)

_____ 1955b. The lodgepole needle miner in Yosemite National Park, progress report of biological studies in 1954. CF&RES, Berkeley, Calif. 14 pp., illus. (mimeo.)

_____ 1956. Biology and control of the lodgepole needle miner, progress report of 1955 studies. CF&RES, Berkeley, Calif. 29 pp., illus. (mimeo.)

_____ 1957. Biology and control of the lodgepole needle miner, progress report of research in 1956. CF&RES, Berkeley, Calif. 29 pp., illus. (mimeo.)

_____ 1958. Biology and ecology of the lodgepole needle miner, progress report of 1957 studies. CF&RES, Berkeley, Calif. 34 pp., illus. (multilith)

Trostle, G.C. 1956a. Study plan for 1956 field test of malathion for the control of the lodgepole needle miner. CF&RES, Berkeley, Calif. 5 pp. (typed)

_____ 1956b. Study plan for the 1956 field tests of endrin, dieldrin, and malathion, against the larvae of the lodgepole needle miner. CF&RES, Berkeley, Calif. 4 pp. (typed)

_____ 1957. Study plan for 1957 aerial spray for lodgepole needle miner, Yosemite National Park. CF&RES, Berkeley, Calif. 6 pp. (typed)